

The thermal decomposition of sodium hydrogen carbonate

Jenny Pham CHH10C, Esme Hatchell

Research Question

How can the equation for the thermal decomposition of sodium hydrogen carbonate be found by heating and analysing a sample of known mass?

Results

Qualitative observations

The initial masses were weighed using both a weigh boat and while in the crucible and lid as demonstrated in Figure 1. However, the final masses were taken by subtracting the mass of the crucible and lid from the mass of the crucible and lid with the products inside.

Because the trials were conducted on separate days, the crucible used for the first trial was replaced with one larger and heavier for the following 2 trials. Additionally, a different model for the scale but same absolute uncertainty replaced the previous on the same day. Soot from the safety flame accumulated on the outside of the crucible, which is visible in Figure 2. When the crucible, lid, and sodium hydrogen carbonate was weighed, the crucible was still hot. For all trials, the crucible was not placed upright perpendicular to the Bunsen burner stand. Like in Figure 2, it was placed in a position appropriate so that the lid would balance when partially off. The position of the crucible varied per trial. The mass lost between heatings varied between trials.

A thin translucent grey-white vapour was observed to have risen from the crucible in the first 2 heatings.

The solid product inside the crucible after heating was white, granular, and mostly consistent with some clumps.

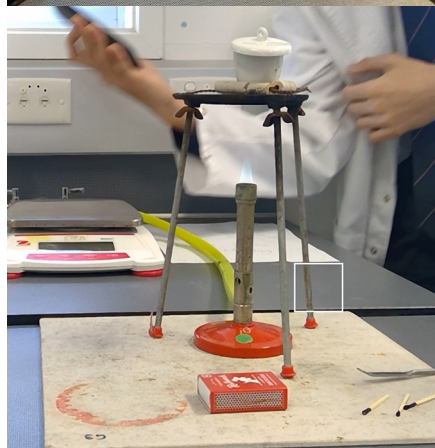


Figure 1 (top): photo of weighing of initial mass using weight boat (Hung)

Figure 2 (bottom): photo of experimental setup during a trial. (author)

Raw data

Table 1 – Raw data showing mass of substances and/or apparatus at various stages of the procedure

Item weighed	Mass (g) ± 0.01 g		
	Trial 1	Trial 2	Trial 3
1. Empty crucible and lid	32.60	38.18	38.18
2. Crucible, lid and NaHC	35.60	41.18	41.18
3. O ₃			
4. Mass of NaHCO ₃	3.00	3.00	3.00
5. Crucible, lid and NaHCO ₃ (after 1 st heating)	34.68	40.10	40.35
6. Crucible, lid and NaHCO ₃ (after 2 nd heating)	34.49	40.08	40.15
7. Crucible, lid and NaHCO ₃ (after 3 rd heating)	34.49	40.06	40.10
8. Crucible, lid and NaHCO ₃ (after 4 th heating)	N/A	40.06	40.10

heating)			
9. Mass of solid left behind in crucible	1.89	1.88	1.92

Sample calculations

Table 2 - Defining Variables

Variable	Meaning	SI Unit
m	Mass	g
MM	Molar mass	g/mol
n	moles	mol

Table 3 - Sample calculations

Calculation type	Example	Uncertainty of calculation (if applicable)
Initial mass of $NaHCO_3$	Weighed, not tared, as shown in Figure 1. All initial masses were $3.00 \pm 0.01 g$	$\%uncertainty = \left(\frac{0.01}{1.88} \times 100 \right) \%$ $\pm 0.531914 \dots \% \approx 0.53 \%$
Mean initial mass	All initial masses are 3.00, therefore calculating the mean is unnecessary.	N/A
Mass of product (final)	$m_{final} = m_{finalfull} - m_{empty\ crucible}$ $\pm 40.10 - 38.18 \pm 1.92 g$	$\%uncertainty = \sum error$ $\pm (0.53 + 0.53) \% \pm 0.0217 \dots \% \approx 1.06 \%$
Mean final mass of product	$\bar{X} = \frac{\sum X}{n} m_{final} = \frac{1.89 + 1.88 + 1.92}{3} \pm 1.90 g$	$absolute\ uncertainty = \frac{ max - min }{2}$ $\pm \frac{ 1.92 - 1.88 }{2} \pm 0.02 g$ $\%uncertainty = \left(\frac{0.02}{1.90} \times 100 \right) \%$ $\pm 1.052631 \dots \% \approx 1.05 \%$
Moles of $NaHCO_3$ in initial mass	$n = \frac{m}{MM} \pm \frac{3.00}{22.99 + 1.01 + 12.01 + 3 \times 16.00}$ $\pm 0.0357\ moles$	N/A
Expected mass $NaOH$ (Eq 1)	$NaHCO_{3(s)} \rightarrow NaOH_{(s)} + CO_{2(g)} 1:1:1$ $m = MM \times n \times ratios$ $\pm (22.99 + 16 + 1.01)(0.0357) 1 \times 1^{-1}$ $\pm 1.42800 \dots \approx 1.43 g$	N/A
Expected mass Na (Eq 2)	$4 NaHCO_{3(s)} \rightarrow 4 Na_{(s)} + 4 CO_{2(g)} + 2 H_2O_{(g)} + O_{2(g)}$ $4:4:4:2:1 m = MM \times n \times ratios$ $\pm (22.99 \times 1)(0.0357) \times 4 \times 4^{-1}$ $\pm 0.820743 \dots \approx 0.83 g$	N/A
Expected mass Na_2CO_3 (Eq 3)	$2 NaHCO_{3(s)} \rightarrow Na_2CO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$ $2:1:1:1 m = MM \times n \times ratios$ $\pm (2 \times 22.99 + 12.01 + 3 \times 16)(0.0357) 1 \times 2^{-1}$ $\pm 1.8919215 \dots \approx 1.89 g$	N/A
Expected mass Na_2CO_3 (Eq 4)	$2 NaHCO_3 \rightarrow Na_2O_{(s)} + 2 CO_{2(g)} + H_2O_{(g)}$ $2:1:2:1 m = MM \times n \times ratios$ $\pm (2 \times 22.99 + 16.00)(0.0357) 1 \times 2^{-1}$ $\pm 1.106343 \dots \approx 1.12 g$	N/A

Percentage yield Eq 5	$\% \text{ yield} = \left(\frac{\text{actual}}{\text{theoretical}} \times 100 \right) \%$ $\left(\frac{1.92}{1.43} \times 100 \right) \% = 134.265734 \dots \%$ $\approx 134.27\%$	N/A
Percentage error Eq 6	$\% \text{ error} = \left(\frac{ \text{experimental} - \text{true value} }{\text{true value}} \times 100 \right) \%$ $\left(\frac{ 1.90 - 1.43 }{1.43} \times 100 \right) \%$ $32.867132867 \dots \approx 32.87\%$	N/A

Processed data

Table 4 - Processed data table for the four possible solid products

Solid product	Expected mass	Actual mass $\pm 0.02 \text{ g}$	Percentage yield	Percentage error
NaOH	1.43	1.90	132.87%	32.87%
Na	0.82		231.71%	131.71%
Na ₂ CO ₃	1.89		100.53%	0.53%
Na ₂ O	1.11		171.17%	71.17%

Analysis of results

The equation that the result has the lowest percentage error to is Equation 3, which is 0.53%. This percentage error for Equation 3 is significantly closer to the expected mass relative to the second closest, which has 32.87% discrepancy. The absolute uncertainty for the experimental value to Equation 3 expected mass is $\pm 0.02 \text{ g}$, and the percentage uncertainty is 1.05%. From Table 4, The range for the percentage yield was from 100.53% (for Na₂CO₃) to 231.71% (for Na). It was observed that the product was similar to the reactants in colour and grain size, however some of the powder was clumped together. Inconsistent losses of mass between heatings in each trial also varied as seen in Table 1.

Evaluation

a) Discussion

To find the true chemical equation for the decomposition of sodium hydrogen carbonate, the other 3 equations must be ruled out.

Equation 1 is not possible because, to remove the carbon dioxide from sodium hydrogen carbonate, the soda has to be in aqueous solution with water. (Imran, 2015). Because the investigation was conducted using solely dry sodium hydrogen carbonate, this equation is not representative of the decomposition reaction that the baking soda had gone under.

Equation 2 is not the equation for the decomposition of sodium hydrogen carbonate because the solid product, sodium, is rarely found in nature in its pure form because of the reactivity of the alkali metal due to its valence shell having only 1 electron. (Pappas, 2011) Its 1 electron is prone to forming ionic bonds with non-metals with incomplete valence shells. Thus, the sodium solid would immediately form an ionic salt with one of the other non-metal products. Additionally, pure sodium appears metallic and opaque. (Britannica, 2021). Unless gone under power metallurgy, which is an extensive 4 step process to granulate metals, pure sodium is usually in a large metallic lattice structure and looks like shards or chunks of metal. (MPIF, 2020) Because it was observed that the solid product was a white powder with small grains, this powder is unlikely to be pure sodium. Additionally, the percentage error from the experimental mass is too large for the product to be sodium.

Equation 4 is not possible because sodium hydrogen carbonate cannot decompose directly into sodium oxide. When the baking soda is heated up to 80 degrees, it decomposes into sodium carbonate by dehydrating the soda, also producing carbon dioxide and water vapour. (Lohner, 2017) This sodium carbonate can further decompose into sodium oxide at 550 °C, a temperature that the Bunsen burner is like to be unable to reach. (Siriwardane et al., 2011). Because the conditions to get a sodium oxide product are not met, Equation 4 is therefore not representative of the decomposition of sodium hydrogen carbonate.

Equation 3 is the correct chemical equation for this decomposition reaction.

When NaHCO_3 decomposes, 2 out of 3 of its products are carbon dioxide and water. Carbon dioxide is released in decomposition reactions because a fraction of the organic carbon is converted into this gas. (Simmons, 2009) Water is released from NaHCO_3 because the ionic compound dehydrates at 80 degrees Celsius. (Lohner, 2017). Both of these products will create a mostly transparent vapour, which was observed to have been produced from the decomposition reaction. Additionally, the solid product was observed to be clumping together. Because sodium carbonate is hygroscopic, it will absorb the moisture in the air from the decomposition reaction. (Juarez-Enriquez et al., 2017). The presence of these two by-products are supporting evidence that Equation 3 is representative of the decomposition reaction of sodium hydrogen carbonate. The solid product will be a compound containing carbon because decomposition, using only heat, only partially removes the carbon in the reactant. (Simmons, 2009) This eliminates all the other equations. Furthermore, the solid product was observed to be white and granular which matches the characteristics of sodium carbonate. (Britannica, 2020) These are the qualitative evidence for the product of the decomposition reaction being sodium carbonate, water, and carbon dioxide.

The discrepancy between the expected mass of the sodium carbonate versus the experimental mass of the unknown solid is the lowest out of all 4 expected masses. The second lowest discrepancy is for sodium hydroxide at 32.87% which is significantly higher than 0.53%. This shows there is little difference between the unknown solid and the sodium carbonate. Because of the obvious distinction in discrepancy, the solid product is quantitatively the most likely to represent the decomposition reaction for sodium hydrogen carbonate.

b) Assessment of Methodology

The result has demonstrated that the methodology was successful in investigating the decomposition reaction of baking soda to a high degree of accuracy and precision. This is evident in the low discrepancy between the true and experimental value, 0.53%, which indicates high accuracy; and the low relative uncertainty for the experimental value, 1.05%, which indicates high precision. Additionally, the expected value lies within the range error for the experimental value which shows the method has produced an accurate and precise result.

Because tool relative uncertainty is higher than percentage error, this indicates that the degree of precision and limit of reading is what is limiting precision. This shows that the methodology has a high degree of precision. Hypothetically, should the percentage error be higher than the percentage uncertainty, this indicates that the error is a sum of uncertainty and an unknown error. This added unknown error is the result of extraneous variables in poor methodological design. Because the result does not show a higher percentage error, this reveals the method is well designed and mitigates extraneous variables.

One of the components of the method that contributes to the high accuracy of the result is the repetitive heating to ensure there are two equal masses. When there are 2 equal data points, this indicates that the products being produced have plateaued, thus indicating all the limiting reagent has been used and the reaction is complete. If this was not done, there would have been no indication that the decomposition reaction is complete. Therefore, the mass would be significantly higher than if it were a complete decomposition reaction. This would have therefore inflated the percentage error and skew the accuracy of the result.

The major component of the method that contributes to the high precision in the relative uncertainty is the use of digital instruments with the appropriate limit of reading. This low range error indicates that the actual mass measured can be in the 1.88 to 1.92 range. From this range, the expected mass for Equation 3 can fit exactly - indicating a high degree of

precision. If the scale be analogue with a limit of reading of 1g (thus $\pm 0.5\text{ g}$), the experimental mass alone is insufficient to distinguish the correct equation because of the large uncertainty range of 1.5g to 2.5g.

However, there are errors that are evident in the result that could have been mitigated. Random error is present in Table 1, where not only are the number of heatings required for the mass to plateau are varied per trial, but different masses are lost between each heating. However, this only mitigates the precision of the result because of the scattering. As shown in Table 4, the accuracy to the expected value is high because of the low discrepancy of 0.53%. The source of this error may be due to the inconsistent positioning of the crucible across trials. In some trials, the crucible was more tilted than others, thus the flame heated the crucible unevenly in one area more than others. The result in the trials, where the crucible is closer to perpendicular to the stand, was that more mass was lost between heatings. This indicates the reaction may be more efficient when heat is distributed more evenly across the crucible. The different masses lost between each heating can be also justified by the initial temperature of the crucible. The first trial lost the most mass between heatings and plateaued the fastest is because the crucible had high initial temperature because of a run previous to it. However, other trials had varying initial temperatures and positioning of the crucible.

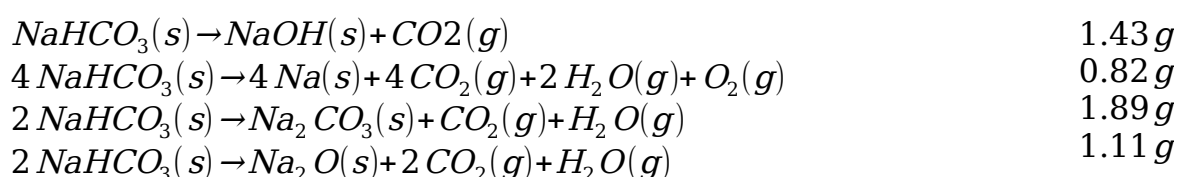
This error can be mitigated by using a crucible made of a material that is an efficient thermal conductor, such as copper, and heating it to 100 degrees before adding the sodium hydrogen carbonate, and conducting more trials. This way, the thermal energy will be quickly and evenly distributed throughout the crucible. This would increase the efficiency of the reaction because the decomposition should immediately happen since sodium hydrogen carbonate decomposes at 80 degrees Celsius. (Lohner, 2017) Consequently, the percentage yield will be closer to 100%. Since there is a consistent initial temperature, the mass lost between each trials will be consistent and predictable, thus mitigating random error. Conducting more trials will create more data points that will balance out the random error in the result.

Additionally, this improvement will ensure the baking soda will be entirely dehydrated, thus there will be no added mass. In the investigation, the product clumping together was observed. This is because the other product, water, is trapped within the powder. This is because sodium carbonate powder is hygroscopic and will clump together when absorbing water vapour. (Juarez-Enriquez et al., 2017) By heating the crucible to the boiling temperature for water, it will be evaporated and there will be no added mass. This will increase the accuracy of the result because the final mass is a more representative of only the solid product. Thus, the experimental mass would be closer to the true mass, and the accuracy of the result will increase.

Systematic error is present in the third trial of the experiment. This is evident in all the values for this trial being consistently higher than the other trials' values. The impact of this error is an anomalous data point which skews the mean mass for the solid product. This results in a higher percentage error and lower accuracy. The source of this error may be the use of 2 different scales between the 3 trials. The scale used for the 3rd trial may have had positive zero error, which caused all the values to shift higher than its actual value. To mitigate this error, using 1 calibrated scale throughout the experiment is recommended.

Conclusion

This investigation aimed to investigate how the chemical equation of a decomposition reaction can be found from comparing the discrepancy between the experimental value and the expected values of the possible products. The possible chemical equations with their expected solid product masses are as follows:



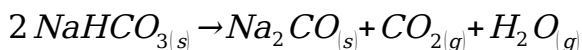
The experimental mass for the solid product is:

$$m = 1.90 \pm 0.02 \text{ g}$$

From eliminating each equation through qualitative and quantitative evaluation, Equation 3 was determined as representative of the decomposition reaction.

This equation had the lowest discrepancy between the expected and experimental mass. The solid product was observed to have the properties and characteristics similar to that of sodium carbonate.

Therefore, the equation, which represents thermal decomposition of sodium hydrogen carbonate to a high degree of accuracy and precision, found from heating and analysing a sample of known mass is:



Reference List

Helmenstine, A. M. (2019). Decomposition Equationi for Baking Soda. *ThoughtCo.*, 1-2. [accessed 18/08/2022]

Juarez-Enriquez, E., Olivas, G., Zamudio-Flores, P., Ortega-Rivas, E., Perez-Vaga, S., & Sepulveda, D. (2017). Effect of water content on the flowability of hygroscopic powders. *ScienceDirect*, 1. [accessed 18/08/2022]

Lohner, S. (2017). Vanishing Baking Soda. *Scientific America*, 1-4. [accessed 19/08/2022]

Metal Powder Industries Federation. (n.d.). *Making Metal Powder*. Retrieved from MPIF.org: <https://www.mpif.org/IntrotoPM/MakingMetalPowder.aspx> [accessed 18/08/2022]

Pappas, S. (2015). Facts about Sodium. *Live Science*, 1. [accessed 18/08/2022]

Philip, W., Marsik, S., & May, C. (1974). *Production of Pure Metals*. Ohio: NASA. [accessed 20/08/2022]